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Wind energy resource assessment of Izmit in the West Black Sea Coastal Region of Turkey

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ABSTRACT

The wind energy potential of Izmit (41.19 N, 30.30 E), which is located in the West Black Sea Coastal Region of Turkey, is assessed with the statistical analysis of the gathered wind data at the 50-m height measurement mast covering the period of 06/2008-06/2009. The annual average wind speed is calculated as 6 m/s and the prevailing wind direction is ENE (60°). The Weibull distribution parameters of shape and scale factor are found as 2.03 and 6.73 m/s, respectively. The measured wind speed data are compared with the data of nearby meteorological stations and the results show that there is a considerable difference between the onsite measurements and the measurements of the meteorological stations. Moreover, a turbulence analysis is carried out and the turbulence intensity is negatively correlated with the normalized height from ground level with canopy height. The energy generation performances of three different wind turbines are evaluated by using the onsite wind speed measurements and the assessment shows that the capacity factor increase by a factor of two from 17% to 34% depending on the type of the turbine. Furthermore, an economic analysis is carried out for a 50 MW wind energy project for the potential site and the proposed project benefit/cost ratio is calculated as 8.

Contents

1. Introduction

Turkey has a considerable wind energy potential with its coastal length of 7.200 km and an average elevation of 1.132 m. However, the country has a complex topography which requires more detailed information for choosing the optimum locations for wind power plants [1]. It was specified by Turkey Wind Energy Potential Atlas (REPA) that there is an 114,173 MW of wind energy potential in regions where wind speed is higher than 7.0 m/s at 50 m height (Table 1). The atlas, however does not allow a detailed examination of the region due to low resolution and high uncertainty [2,3]. The West Black Sea, Marmara, Aegean, and East Mediterranean coastal regions are appeared to be the most suitable sites for wind energy development in Turkey (Fig. 1). Canakkale and Balikesir, cities located on North Aegean and Marmara coastal areas, are alone responsible for 23.5% of the country's wind energy potential (Fig. 1).

After the enactment of the Turkish Renewable Energy Law in May 2005, the wind energy project owners have received a guaranteed price of 73 $/MWh for the generated electricity for a duration of 10 years under the feed-in tariff mechanism. This support scheme has given rise to a dynamic growth of wind

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energy projects in Turkey: the total installed capacity of wind energy which was 18 MW by the year 2004 reached to 2312 MW by 2012. Turkey's objective is to reach 20 GW of installed capacity by 2023 [2].

Several researches used the wind speed data of the meteorological stations to assess the wind energy potential of coastal regions in Turkey (Table 2). In addition to these studies, wind speed estimation of the target station in the Southeastern Anatolian Region of Turkey was carried out by determining wind speed correlation between neighboring stations and using Artificial Neural Network (ANN) [10]. Similarly, ANN was also used for short term estimation of wind speed in the region of Batman, Turkey [11]. For the western region of Turkey, wind energy potential of Kırklareli was examined by use of statistical data of the last three years [12]. But, neither of those studies questioned how representative and reliable the meteorological wind speed measurements for the assessment of the coastal wind energy potential of the country. Common problems include height of anemometer is low ($y = 10$ m); anemometer mast is surrounded by obstacles like buildings and trees (Fig. 2). Therefore, the uncertainty of coastal wind energy assessment based on meteorological datasets is expected to be high.

Table 1
Wind power potential of Turkey by regions where wind speed is higher than 7.0 m/s at 50 m height. The raw data was obtained from EIE [4] for each of the cities located in the region and the wind power potential of the regions was calculated by the authors.

Region	Wind power potential (MW)	Percentage
Aegean	26,150	22.9
Marmara	43,917	38.5
Mediterranean	11,214	9.8
Black Sea	14,312	12.5
Eastern Anatolia	2974	2.6
Central Anatolia	10,904	9.6
Southeastern Anatolia	4703	4.1

This study aims to evaluate the wind energy potential of Izmit which is located in the West Black Sea of Turkey. For this purpose, one-year wind speed records of a measurement mast are assessed and compared with the data of nearby meteorological stations. Moreover, a statistical analysis is performed to evaluate the wind energy potential of the site and an economic analysis is carried out for a 50 MW wind energy project for the potential site.

2. Wind energy resource assessment

The starting point of any wind energy project is the resource assessment. It helps to identify suitable sites for wind turbines and also undertake an early economic cost analysis. Due to the rather large capital investment involved with wind energy projects, it is crucial to undertake the resource assessment as precisely as possible. The speed of the wind and its annual frequency are key parameters that determine the net output of a wind turbine.

Wind turbines convert air flow kinetic energy into mechanical energy, which can be used to drive an electricity generator. Wind turbines can convert as much as 50% of the available wind energy into electricity and power output P of the wind turbine is expressed by the following formula:

$$P = \frac{1}{2}\rho A V^3 C_p \tag{1}$$

where ρ is the density of air and it is assumed to be 1.225 kg/m^3, A is the swept area, V (m/s) is the wind speed, and C_p is the power coefficient of the wind turbine for the corresponding wind speed. Wind energy generation is a cubic function of wind speed and this implies that small changes in wind speed estimates can cause large changes in wind energy estimates. In recent years, Weibull distribution has been one of the most commonly used, accepted, and recommended distribution to determine wind energy potential and it is also used as a reference distribution for commercial wind energy software such as Wind Atlas Analysis and Application Program (WASP) [13]. Its probability density function (PDF)

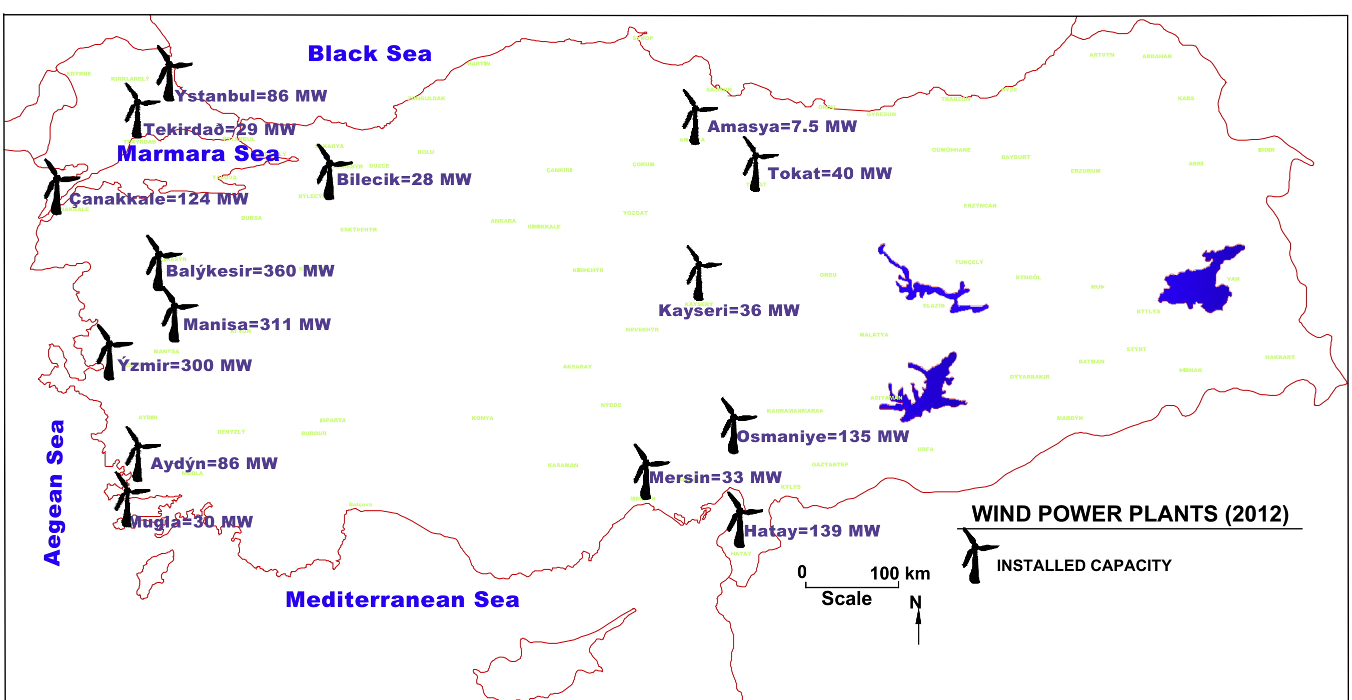

Fig. 1. Distribution of wind power plants in Turkey by May 2012. The wind parks grouped based on cities.
Source: EMRA [5].

Table 2
Recent coastal wind energy resource assessment studies using the meteorological stations of Turkey.

Reference	Data source	Wind resource conditions
Akpınar [6]	Meteorological stations of Middle-East Black Sea Region.	Annual mean wind speed in this region ranges from 1.73 m/s to 2.85 m/s. Highest wind power potential found at Sinop and Hopa.
Erdoğan et al. [7]	Meteorological stations of West-Middle Black Sea Region.	Annual mean wind speed in this region ranges from 1.25 m/s to 2.5 m/s covering the period of 2001–2010. Sinop appeared to be the most promising region for the wind energy development.
Ucar and Balo [8]	Meteorological stations of all coastal regions.	The annaul average wind speeds of the coastal regions in Turkey were found as: Black Sea=2.4 m/s, Marmara=3.3 m/s, Aegean=2.6 m/s, and Mediterranean=2.5 m/s.
Sahin et al. [9]	Meteorological stations of Mediterranean Sea Region.	At the Eastern Mediterranean Region, the mean wind speed ranged from 0.8 to 4 m/s covering the period of 1992–2001. The most promising locations for wind power potential were found in Iskenderun, Antakya and Samandağ.

Fig. 2. Photo of a typical meteorological station surrounded by buildings and trees in Turkey. The meteorological station is located in Zonguldak (41.45 N, 31.78 E), North-West of Turkey.

Table 3
Coordinates of the measurement mast, Akçakoca and Şile meteorological stations.

Measurement location	Coordinates	Altitude (m)
Measurement mast	Lat: 41.193 N, Lon: 30.305 E	77
Akçakoca meteorological station	Lat: 41.089 N, Lon: 31.137 E	10
Şile meteorological station	Lat: 41.169 N, Lon: 29.601 E	83

is defined as

$$PDF = (k/A)(V/A)^{k-1}\exp(-(V/A)^k) \tag{2}$$

where k and A (m/s) are the shape and scale factors of the Weibull distribution, respectively.

The wind speed changes with respect to height from ground and vertical distribution of wind velocity is described by:

$$\frac{V_2}{V_1} = \left(\frac{y_2}{y_1}\right)^{\alpha} \tag{3}$$

where V_2 and V_1 wind speeds at heights y_2 and y_1, and α is the shear coefficient. Shear coefficient is used to extrapolate the horizontal component of wind velocity to different heights.

3. Assessment of the wind energy potential in the coastal region of Izmit

A 50 m-height measurement mast was installed by 3E in the coastal region of Izmit. Its coordinates and an overview map are given in Table 3 and Fig. 3, respectively. The measurement mast equipped with six anemometers (NRG #40+Thies) at three different levels (50, 35 and 20 m), and wind vanes at 48 m and 38 m. The anemometers were individually calibrated and calibration parameters were correctly introduced in the data logger. The wind data (average and standard deviation of wind speed, wind direction) recorded at ten minute intervals. The uncertainty on the measured wind speed is ± 0.2 m/s. The measurement campaign covers the period 06/2008-06/2009. Locations of the measurement mast and the nearby meteorological stations of Şile and Akçakoca are shown in Fig. 3. The measurement site is forest land which consists of a hill reaching to a height of 120 m.

In order to make a comparison between the measurement mast and nearby meteorological stations, the wind speeds of mast measurement were extrapolated to the same levels of the meteorological stations. As shown on Fig. 4, wind speeds measured by those public meteorological stations show similar trends when compared to the mast measurements, but are clearly lower values (average of 6 m/s on site, 1.30 m/s in Şile and 1.65 m/s in Akçakoca). This could be explained by the intense roughness (trees growing and new buildings) in the surroundings of the meteorological stations. The monthly average wind speeds of the measurement mast at 50 m height are presented in Table 4. The highest wind speed regime is observed in the winter season.

The frequency distribution of the wind speed shows that 75% of the wind speed values are distributed between 3 and 9 m/s (Fig. 5). The Weibull distribution parameters of k and A are found as 2.0 and 6.73 m/s, respectively. The frequency rose shows a very important frequency at the north-east directions (based on a 16-direction distribution) for which the mean wind speed values are the most relevant and the prevailing wind direction is ENE (60°) (Fig. 6).

4. Turbulence analysis

In the literature there are many studies on the evaluation of wind energy potential of Turkey in terms of the assessment of the wind speed and wind direction aspects [6,12]. But, those studies are lack from turbulence characteristic analysis; although Turkey is situated through a mountainous and complex terrain. The turbulence analysis of a site is important because wind turbines are

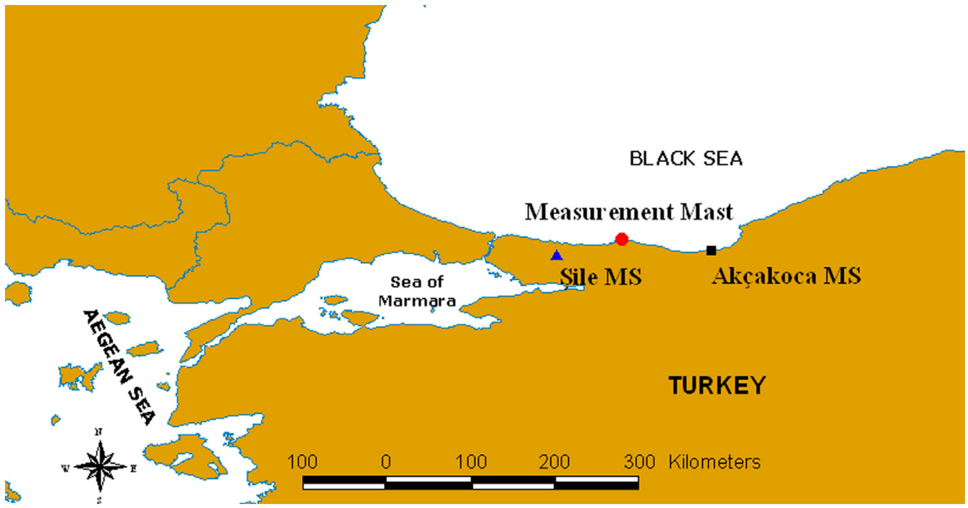

Fig. 3. Locations of the measurement mast and the meteorological stations of Şile and Akçakoca.

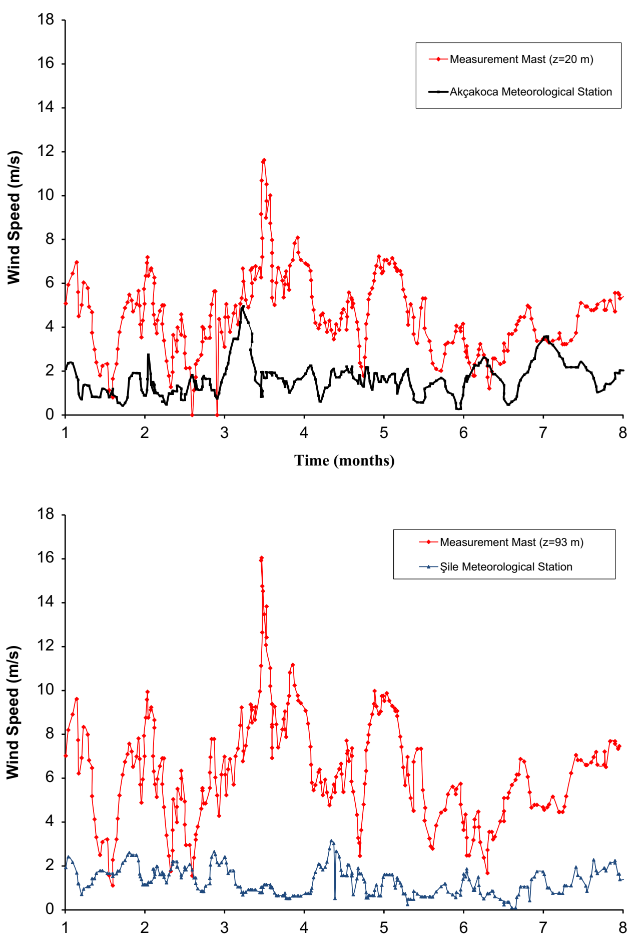

Fig. 4. Comparison of the wind speeds in measurement mast and meteorological stations of Akçakoca and Şile.

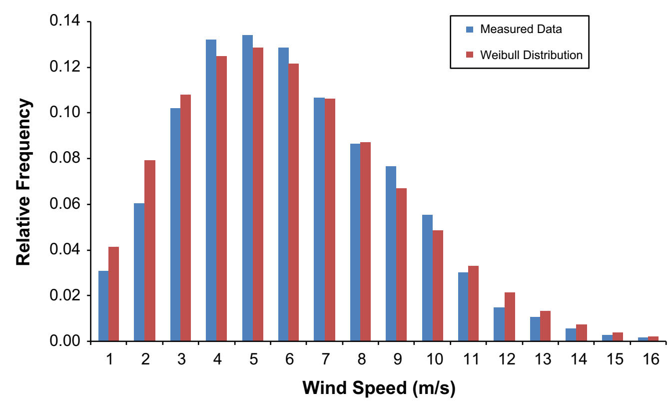

Fig. 5. Frequency distribution of the wind speed in the mast measurements and Weibull fit.

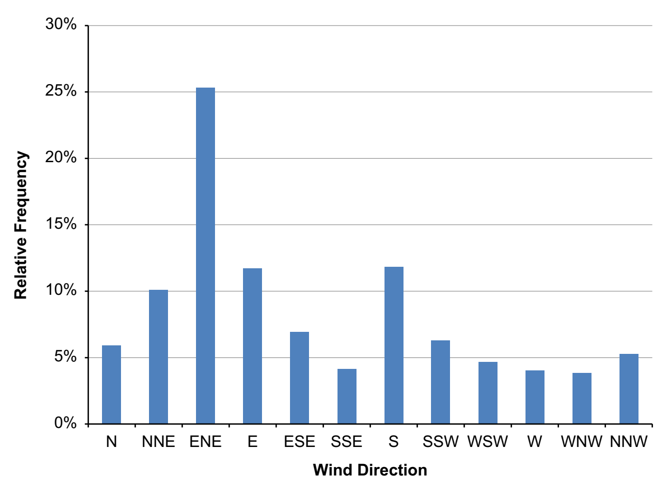

Fig. 6. Frequency distribution of the wind direction in the mast measurements.

Table 4
Mean monthly wind speed values for mast measurements covering the period of June 2008–June 2009.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Wind speed (m/s)	6.8	7.3	6.1	5	4.7	5.1	5.3	6.4	6.5	6.4	5.8	6.9

designed based on the wind speed and turbulence characteristics of the particular site. Also, wind turbulence significantly influences the fatigue loads acting on the wind turbines and high level of turbulence causes reduction in energy output and it speeds-up the fatigue of the mechanical parts of wind turbine [14,15]. Turbulence Intensity (*TI*) is defined as the standard deviation of the 10-min

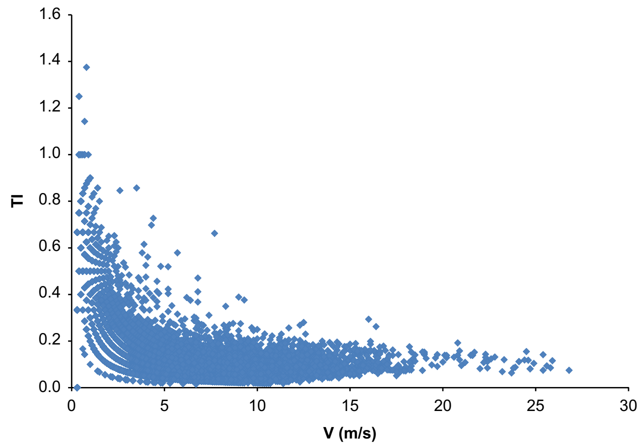

Fig. 7. Turbulence intensity *TI* versus wind speed *V*.

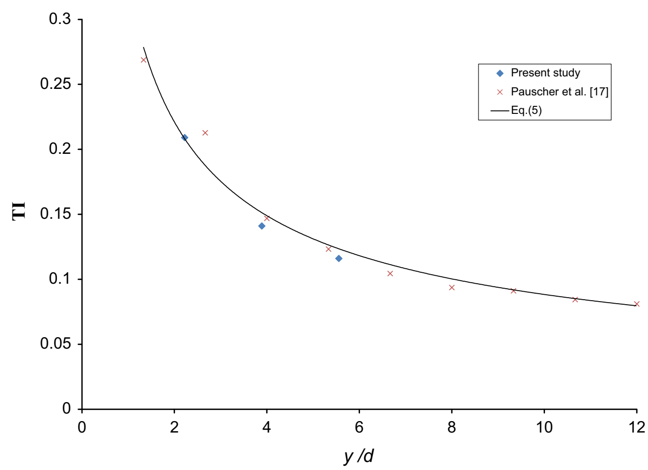

Fig. 8. Turbulence intensity *TI* as a function of normalized height from ground level *y*/*d*. *Note*: *d* denotes canopy height and it has a value of 9 m for the present study and 15 m for the study of Pauscher et al. [17].

Table 5
Annual wind energy yield of the mast measurements for different wind turbines of Enercon.

	E82	E101	E115
Rated power (kW)	3000	3050	2500
Rotor diameter (m)	82	101	115
Swept area (m^2)	5281	8012	10,387
Rotational speed (rpm)	6–18	4–14.5	3–12.8
Gross yield (MWh/year)	4662	6776	7460
Capacity factor (%)	17.6	25.4	34.1

measured wind speeds,

$$TI = \frac{\sigma}{V_{avg}} \qquad (4)$$

where σ is the standard deviation of the wind speed and V_{avg} is the average of the wind speed for 10-min. A value of *TI* that is 0.10 or less is regarded as low level turbulence; *TI* in the range of 0.10–0.25 is regarded as medium level turbulence; 0.25 or higher regarded as high level turbulence [14]. In the present study, the mean turbulence intensity at 50 m height is calculated as 0.116 indicating that site has medium turbulence level.

In Fig. 7, *TI* is plotted as a function of wind speed and as can be clearly seen from the Fig. 7 that the turbulence intensity has a tendency to decrease with higher velocities which is consistent

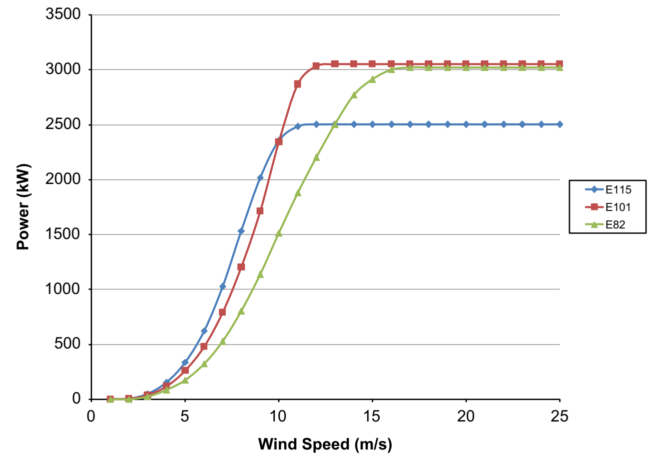

Fig. 9. Power curves of different type of Enercon wind turbines.
Source: Enercon [18].

Table 6
Economic analysis of a 50 MW wind energy project in the measurement site.

Installed capacity (MW)	50
Capacity factor (%)	34
Gross annualenergy (MWh/year)	149,196
Net annual energy (MWh/year)	140,244
Investment cost (EUR)	60,000,000
Revenue (EUR/year)	7,811,590
O&M costs (EUR/year)	841,464
Net revenue (EUR/year)	6,970,126
Benefit/cost ratio	8

with IEC [16] normal turbulence model. In Fig. 8, the turbulence intensity *TI* is plotted against the normalized height from ground level *y*/*d*. Here, *d* denotes the canopy height which is 9 m for the present study. The turbulence intensity decreases from 0.209 to 0.116 for $y/d=2.22$ to $y/d=5.55$, respectively (Fig. 8). This is due to the fact that the canopy influence on air flow decreases with relative height. Also, to make a comparison, the data of Pauscher et al. [17] are plotted in Fig. 8. It should be noted that Pauscher et al. [17] collected wind speed data at a 200 m measurement mast with 20 m intervals in a similar terrain (sloping forest) but with higher canopy height ($d=15$ m) in Kassel, Germany. In their study, very high turbulence intensities ($TI=0.27$) are observed close to the forest canopy ($y/d=1.33$) and the intensity rapidly decreases ($TI=0.12$) up to $y/d=5.33$. Fig. 8 depicts the negative relationship between the turbulence intensity and dimensionless height and this trend was best fitted by

$$TI = 0.32(y/d)^{1/1.77} \qquad (5)$$

with a correlation coefficient of 0.98. However, the validity of Eq. (5) should be tested at different canopy conditions. The data indicate that wind turbines are subject to less turbulent loads at higher levels.

5. Economic analysis of a wind energy project at the measurement mast

Three different Enercon wind turbines (E82, E101, and E115) are selected for the energy yield assessment in order to find most suitable wind energy converter for the potential site (Table 5). The power curves of the Enercon wind turbines are given in Fig. 9 and

each turbine has different power curves based on their rotational speeds.

The Enercon wind turbines are used in the assessment; because the power curves of Enercon wind turbines provide highly reliable and realistic calculations for expected energy yield based on the wind conditions at the respective site taking into account the average turbulence intensity of 12% [18]. The E115 wind turbine has the highest capacity factor with a value of 34% and this turbine is selected for the economic analysis. Here, capacity factor is defined as the net annual energy yield divided by the maximum theoretical production of the wind turbine; this turbine operated at rated power during 8766 h of the year.

The economic analysis is carried out as a conventional cost-benefit analysis, where the costs of the wind energy project are compared with its benefits. The value of this benefit is equal to the revenues from the sales of electrical energy based on the applicable feed-in tariffs. Additional revenues by selling CO_2-certificates are not feasible at the moment. Revenue generated from a wind energy project is computed from

$$R(i) = \Pr(i)E(i) \tag{6}$$

where i is the period, $R(i)$ is the revenue in period i, $\Pr(i)$ is the electricity sale price in period i, and $E(i)$ is the amount of electricity generation in period i. Benefit/cost ratio, B/C, is calculated from

$$B/C = \frac{R - O\&MC}{O\&MC} \tag{7}$$

where R is the annual revenue and $O\&MC$ is the annual operational and maintenance costs. It is a simple benefit/cost calculation without debt contracting from financial institutions.

Based on the EWEA [19] calculations, approximately 75% of the total investment cost of wind power plants is related with turbine costs; while, grid connection and civil works are responsible of 8.9% and 6.5% of total cost, respectively. The investment cost structure of the wind power plants in Turkey is consistent with the EWEA [19] calculations and unit investment costs have values in the range of 1000–1300 €/kW [3]. An economic analysis of a 50 MW wind power plant for the measurement site is presented in Table 6. In the economical assessment, the unit investment cost and O&M costs (including insurance, regular maintenance, administration, and staff salaries) are taken as 1200 €/kW and 0.6 €-ct/kWh, respectively and those values are confirmed by several wind energy projects in Turkey [3]. Also, the assessment is based on the financial assumption for which a debt-equity ratio of 0:100 is taken. This means that 100% of the total project costs will be financed through equity and there will be no debt payments. Considering the wind energy roses obtained from the measured data, 25 wind turbines should also be located preferably along the NNW/SSE (150°) direction to mitigate wake effects. The wake and operational energy losses are assumed to be 6% of the annual energy yield and the net energy yield is calculated as 140,244 MWh/year. The feed-in tariff price of 55.7 €/MWh yields the annual revenue of the power plant as 7.8 million Euro (Table 6). The project will pay no taxes. As a result, the proposed project has a benefit/cost ratio of 8 indicating that project generates sufficient revenues to cover its O&M costs.

6. Conclusions

The conclusions of the study can be summarized as follows:

(a) It is discussed that, the wind speed data from the meteorological stations in Turkey can be insufficient to ensure a reliable wind energy resource assessment for the coastal regions. A great attention should be given when using the wind speed data of the meteorological stations of Turkey for the calculation of the coastal wind energy potential.
(b) The wind energy potential of coastal region of Izmit is evaluated by using one year onsite measurements. It is seen that the localities with measurement masts in the region are characterized by higher wind speeds compared to other localities with meteorological stations. In average, the wind speed values of measurement mast are 5 and 2.8 times higher than the Şile and Akçakoca meteorological station values, respectively.
(c) The assessment of the turbulence data shows that the turbulence intensity depends on the normalized height from ground level with canopy height.
(d) It is shown that wind turbine type has a significant impact on the annual energy yield. The economic assessment indicates that the proposed wind energy project is financially feasible.

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